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Digital Image Analysis: Part I-Detection Of Color Uniformity In Dyed Textiles

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Abstract

An image analysis system based on a video camera, personal computer equipped with a black/white frame grabber board, and peripheral monitors and printers was configured to capture the digital images of dyed fabrics. Applying the data acquired by this system, two indices were developed to measure uniformity of color in dyed cotton and wool/cotton textiles. In the case of all cotton dyed with direct dyes, levelness of shade was quantified from the Level Shade Index. In the case of wool/cotton blended fabrics, the ability of pretreated wool/cotton textiles (dyed without tone-on-tone effects) to dye to the one shade was measured from the Union Shade Index.

The linear relationship between colorimetric lightness, L*, and the gray-scale mean of the histogram of the digital image indicated that the mean value, whether high (lighter shade) or low

(darker shade) could be used to assess changes in the relative dyeabilities of pretreated wool and cotton fabrics. Image analysis extends the utility of colorimetry by providing the potential to measure level and union shades.

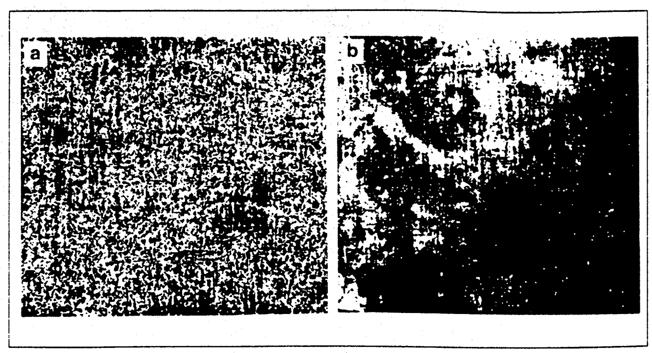
Introduction

Appearance is generally regarded as the most important textile attribute for consumer acceptance and enduse. The quality of the appearance of fabrics and fabric blends has psychological applicability to the perception of a fabric's performance and useful life. Textile manufacturing industries are concerned with the appearance of color uniformity in terms of levelness in dyed fabrics and/or union shade in dyed fabrics of more than one fiber-type. Color quality, rather than uniformity, is traditionally measured by colorimetric methods that rely upon measurement systems such as the Commission International de l'Eclairage's CIELAB that employs lightness, (L*), redness or greenness, (a*), and yellowness or blueness, (b*) measurements.

While on-line adaptation of this system for quality control and shade-sorting provides important guidance for the development of new and useful textile products, it offers limited utility in qualifying and quantifying uniformity of shade. Dyeing processes that lead to uniformly distributed color are a major concern of companies producing "levelers," "retarders," and "fixing agents' for textile dyeing applications. Thus there is a pressing need to develop quick and efficient monitoring methods to complement colorimetry that can be placed online for rapid determination of shade defects.

A simple monitoring system employing machine vision is derived from the configured system of a charged-coupled device (CCD) camera linked to a personal computer (PC) containing a frame-grabber board, peripherals, and software for image access, process, display, and manipulation. Using such a system, a fabric's analog or actual image is collected, digitized, and displayed in shades of gray as a histogram display of pixel distribution over a grayscale range. The histogram features are used to measure color uniformity. This process is commonly referred to as "dig-

Figure 1–Digital image of cotton fabrics dyed with direct dyes: (a) - level-dyed cotton fabric, D80, (b) - unlevel-dyed cotton fabric, D81.



ital image analysis."

Early textile applications of image analysis have relied upon certain mathematical functions to manipulate and improve gray scale video For example, the appearance of fabrics with wrinkle-resistant finishes was evaluated from the histogram displays of the digital images of the fabrics[1-3]. Wood and Robson (1989), Wood (1990), and Wood, Wang, and Robson (1991) developed algorithms to measure carpet appearance from edge-detection filtering and Fourier transform conversions of the images[4-6]. Others have used image analysis to characterize textural changes in carpets with wear[7-10], and seam pucker in fabrics[11].

Colorists became acquainted with these ideas in the 1970's when judd and Wyzecki inferred that television cameras could be used for automatic color measurement. This concept was not implemented until the development of the solid state camera that offered greater signal stability and the digitizer that allowed the image to be captured by the camera for computer processing. Now, these units are combined in automated fabric inspection systems and they incorporate algorithms to emulate human visual perception. Currently, CCD video cameras, frame grabber boards, filters, and central processors are used for on-line detection of fabric defects. On-line detection of color is not as advanced.

Although colorimetric systems offer a vast assortment of tasks. they are usually dedicated to measuring the CIELAB parameters, delta L*, a*, b* for color quality and delta E* for color tolerance in the continuous dyeing range. They offer little utility for monitoring color uniformity. To address this issue, manufacturers of colorimetric equipment are designing digital camera systems to measure the color and appearance of materials for on-line applications. These systems generally employ a three-chip CCD camera with separate detector array for the red, green, blue (RGB) color primaries and they provide pixel-by-pixel color analysis of the image and color definition in terms of CIELAB attributes.

Experimental

Materials:

Camera System and Imaging

One can readily configure a simple image analysis system with camera, lenses, and digitizing board for under

Table I: Shade Characterization and Image Analysis for Level Shade of Cotton Fabrics Dyed with Direct Dyes.

Sample	L*[a]	K/S[b]	Mean[c]	SD[d]	LSI,%[e]
D80-1	41.2	12.4	94.4	11.7	-4.9
D80-5	42.9	10.5	83.8	12.2	-0.81
D80-6	43.1	10.1	85.3	12.9	4.90
D80-Average	42.4	11.0	87.9	12.3	0.0
D81-1	45.9	7.52	100	18.1	47.2
D81-2	49.6	5.62	110	18.0	46.3
D81-3	46.6	5 56	92.8	14.8	20.3
D81-Average	47.4	6.23	101	17.0	38.2
Gray Card			66.6	7.68	

[a]Lightness value, CIELAB
[b]Color strength parameter
[c]Average value of the gray-scale histogram
[d]Standard Deviation of the gray-scale histogram
[e]Level Shade Index relative to D80-Average

Table II: Shade Evaluation of Pretreated and Dyed Wool/Cotton Union and All Wool Fabrics.

Sample	Fabric	Dye	Pretreatm	K/S	Mean	SD	G
24	union	Reactive Red 2 3%	none	5.29	130	44.6	45.2
39	union	Reactive Red 2 3%	Resin/CC	21.8	81.9	24.9	24.8
31	wool	Reactive Red 2 3%	Resin/CC	22.1	79.8	25.2	25.8
WUTR	wool	Reactive Red 65 3%	none	23.6	105	21.1	21.1
WUTD	wool	Direct Red 79 3%	none	27.5	65.9	18.8	18.9
UUTA	union	Acid Red 114 2%	none	1.63	125	50.6	50.1
2SAN	union	Acid Red 114 2%	Sandene 8415 Liqui	20.6	90.2	25.7	26.3
2SOL	union	Acid Red 114 2%	Solfix E	20.1	90.8	26.4	26.8
2LEV	union	Acid Red 114 2%	Levogen	11.9	104	27.4	27.5
gray card					137	14.0	13.9

S10,000 at current prices. Our system is interfaced with a computer having 486MByte-DX2, 66MHZ clock speed, 8MByte random access memory, and 420MByte hard drive capacity. Dedicated software running under Microsoft™ Windows™ 3.1 provides easy use and a comprehensive array of utilities for image enhancement, data extraction and analytical functions to solve a broad scope of analytical problems. Image analysis can be used with black/white (BW) or color images. Color has been used less because of the difficulty in controlling the lighting and relating the camera RGB's to the visual perception of color. The configuration of the system to measure level and union shades in dyed textiles has been reported elsewhere[12-14]. A black/white Frame Grabber Board was used, thus, all images described below are achromatic.

Level shade

Unbleached, mercerized cotton (400M, Testfabrics, Middlesex, New Jersey)[a] was dyed with C.I. Direct Red 80 (molecular weight = 1345g/M) and with C.I. Direct Red 81 (molecular weight=603 g/M), respectively. When the fabrics (D81) dyed with C.I. Direct Red 81 were rinsed after dyeing, color was lost and the shades of these fabrics were not level.

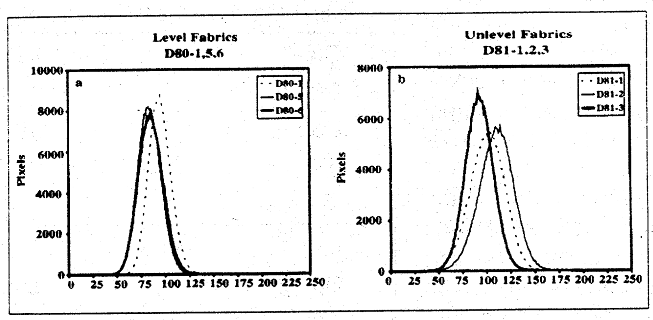
However the shades of fabrics (D80) dyed with the higher molecular weight dye, C.I. Direct Red 80, were level. Because of the larger size of this dye, it was able to aggregate after sorption, thus precluding color loss.

The camera conditions for the image captures of these fabrics were as follows: camera mode - auto; macro lens setting - 50 mm; camera aperture - f 8-11, green camera filter, camera distance - 37.8 inches, and area of interest - 7"x5" (18cm x 16 cm). The images were background subtracted against the 18% reflectance gray-card.

Image capture involved the following sequence and image manipulations:

- Acquire the image of the gray-card to be used as a background. Store it in the 1024x1024x8 bit frame grab ber buffer.
- Acquire the image of the fabric and store it similarly.
- Subtract the background image from the fabric image and display it.

Figure 2–histograms of cotton fabrics: (a) - dyed to level shade with C.L Direct Red 80; (b) - dyed to unlevel shade with Direct Red 81.



- Perform analysis on the digital image in two ways:
  1. Analyze the binary (black and white) image.
  2. Analyze the histogram (pixel distribution over the gray-scale range) of the fabric's digital image as a 262K image of 512x512 pixels in 256 gray levels.

Binary Image

The *binary image* (black and white) depicts a specific range of intensities that have been selected as "white" while all other intensities are "black." This feature of segmentation is often referred to as thresholding. It is used to depict the specific features of an image by reducing images to black and white representations of features and background. The corresponding binary images of the fabrics in Figure I (a) and (b).

Note the large irregularly shaped light and dark areas in the unlevel fabric, D81, indicating nonuniform coloration. Note the fairly uniform pattern of black and white in the level fabric D80, where the black and white areas are oriented vertically and horizontally for uniform coloration.

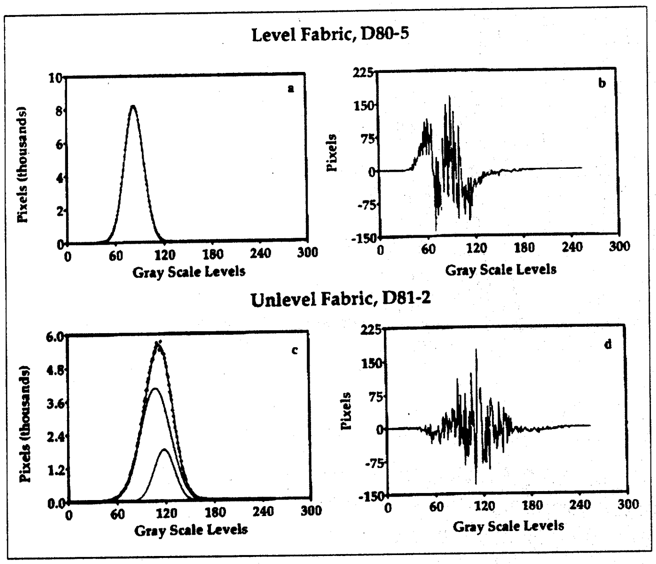


Figure 3–(a) - Curve-fib of the histograms of dyed cotton fabrics: (a) Level-dyed D80 with normal Gaussian distribution; (b) - unlevel D81 fit to two curves; (c), (d) - goodness of fits shown by random error displays of the data points of the supposition peaks used to fit the main histograms.

Using binary images, it is possible to map for shade variation after dyeing. Threshold values for the binary images were based on the mean gray levels and standard deviations for the D80 and D81 histograms. These segmented images show the distribution of pixels above, within, and below the first standard deviation from the mean gray level within the image. All gray values below or above the mean appear white and black, respectively. The resultant images dramatically display any color variations. In Figure 1 (a) the binary image segmented from the digital image has highlighted distribution of pixels uniformly spread over the entire image area in a narrow range of the gray levels, 88-98. In Figure 1 (b), the binary image has highlighted distribution of pixels in an irregular pattern located in the upper left of the image in the narrow range of gray levels, 66-76.

Histogram Image

The *histogram image* depicts the brightness and contrast characteristics of the image. Images with low contrast will have a pixel distribution over a very narrow gray-scale range. Thus the shape of the histogram, whether high, narrow, and symmetrical (typical for level-dyed fabrics) or low, broad, and skewed (typical for unlevel-dyed fabrics) is descriptive of uniformity of coloration. For determining level shade, the histogram,s breadth or standard deviation is taken to indicate level shade, that is, small values for level-dyed fabrics and large values for those that are not level-dyed. Also, the histogram mean indicates lightness-darkness with the 0-256 gray scale axis representing dark-light (respectively) color values.

The histograms of level-dyed fabrics, D80-1,5,6, shown in Figure 2, are from replicate dyeings with C.I. Direct Red 80. The histograms for each fabric show the distribution of the maximum number of pixels (the same for all histograms) over a gray scale range. The fact that the peak heights are nearly the same suggests that the standard deviations are nearly the same.

Closer examination of the histogram of one of the level fabrics, D80-5, in Figure 3 (a), shows that a single Gaussian curve is sufficient to fit the data when curve-fit by nonlinear regression techniques. The plot of the residuals in (c) shows a rather random pattern of errors. By contrast, the histograms of unlevel-dyed fabric, D8 1-2, in Figure 3 (b), has a lower peak height than D80-5. Thus, the standard deviation in (b) is greater, indicating unlevelness by contrast. Note also that the histogram in (b) shows skew deviation from Gaussian shape and requires two curves to provide a good model. The plot of the residuals in (d) shows that deviations from this model are random.

When the average histograms of the level and unlevel fabrics are compared to that of the gray card standard, the D80 fabrics show a broader but yet relatively narrower distribution relative to the average histogram of unlevel D8 1 fabrics in Figure 4.

Level Shade Index

The *Level Shade Index* (LSI) in Equation 1 has been proposed in order to compare the standard deviation of an experimental dyed fabric to the standard deviation of a standard that represents a level-dyed fabric[12].

1. Relative to a level fabric of the same fabric type:

Level Shade Index, $LSI=(S-S_o)/S_o x100$

Equation 1

Where S is the standard deviation of the sample in question and S0 that of the level sample. A value of 45 for this index indicates that a dyed fabric has a standard deviation 45% larger than that of a level fabric.

Level Shade indices for each of the samples are shown in Table I. By this equation, where there is no difference between the sample and the standard, $(S-S_o)=0$. In this case. the dyed fabric has a Level Shade Index of 0 % and the fabric is as level-dyed as the standard. In Table I, level-dyed fabrics have negative or low LSI values. The LSI values for unlevel fabrics are markedly high by contrast. Note that fabric D8 1-3 exhibits roughly twice the levelness of the other two samples.

2. Relative to Standard 18% Reflectance Gray Card

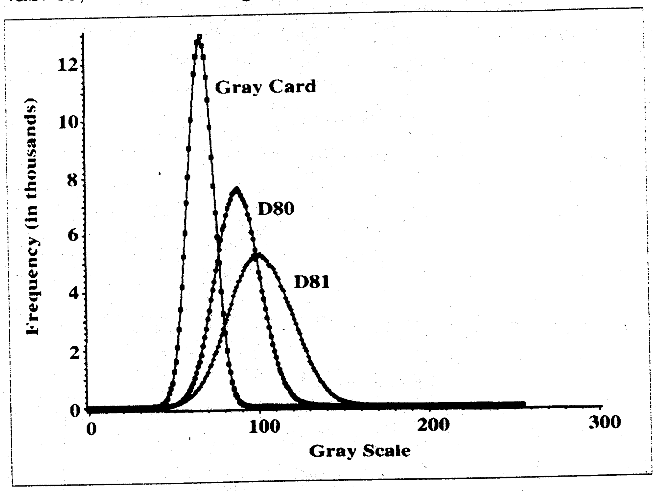
In this case, S_o represents the standard deviation due to lighting conditions only and is represented by the gray-card in equation 2.

$LSI=SD_{gray\ card}/SD_{sample}\ x100$

Equation 2

By this Equation direct comparison can be made between the dyed sample and the gray card or a selected sample perceived as level in place of the gray card. A value within 90% to 100% would indicate level shade. From Table II, using the gray card as standard, D80 fabrics average 62% level shade and D81 fabrics, 45%. However D80 fabrics appear visually to be level shades. Clearly it is not necessary to measure levelness outside the limits that the eye can see for uniform shade. The level fabrics, D80, are therefore more suitable than the gray card for the term, S_o, in Equation 1. In this case, D81 fabrics have a level shade index of 72%.

Figure 4–Comparison of the breadths of the histograms for the gray card standard, the average histogram of level D80 fabrics, and the average histogram of unlevel D81 fabrics.



Note in Table I that the CIELAB lightness, L*, is inversely proportional to the histogram's mean value. Recall that the digital images of the lighter fabrics have pixel distributions at the higher gray-scale values. Also note that the K/S values for the unlevel D81 fabrics are half those of the level D80's. This shows the effect of dye loss and resultant lighter shades[15].

Union Shade

In wool/cotton union blends where the wool and cotton yarns are interlaced in the weaving and in intimate yarn blends of wool and cotton, dyeing from a single bath is cumbersome. These processes require one or two baths with one or two dyes. These processes also require different conditions for pH and temperature. Wool and cotton are dyed sequentially or together by incorporating a retarding agent for the wool. Recent reports on facile, one bath/one-dye systems for union dyeing wool/cotton with acid, direct, and reactive dyes describe a pretreatment step[16-19]. The pretreatment can be either resin/quaternary amine (choline chloride, CC), resin/amine, or a fiber-reactive dye fixative. In the pretreatment step, cotton is selectively modified without affecting wool so cotton in the wool/cotton blend will dye similarly to wool.

The histograms of some of these dyed samples are shown in Figures 5, 6, and 7. Image capture involved the following camera accommodations: manual camera setting - 75mm with 40mm extension tube and +4 magnifying lens, camera aperture - f 16, camera position - one inch from the fabric to capture the brightness of the dyed wool and cotton yarns.

Union Shade Index

For the objective measurement of union shade, a Union Shade Index, G, was derived. The G index is based on fitting the histogram of the sample to two or three curves. It accounts for the standard deviations, mean values, and areas of the individual curves. The G value is a measure of the spread of the histogram of the sample. For a sample whose shape can be represented as a single Gaussian peak, G is defined as the standard deviation of the peak.

$G^2=S^2$ Equation 3

where S is the standard deviation. For a sample whose shape is a superposition of two Gaussian peaks, G is defined as

$G^2=(A_1/A)S_1^2+(A_2/A)S_2^2+(A_1A_2/A^2)(X_1-X_2)^2$

Equation 4

where A_1 and A_2 are the peak areas of the two Gaussian peaks. $A=A_1+A_2$ is the sum of areas. S_1 and S_2 are the standard deviations. X_1 and X_2 are the positions of the two peak means. This formula can be demonstrated to be the standard deviation of the superposition of the two Gaussian peaks. It is fully symmetrical between the two peaks and, as one might expect, G^2 contains terms proportional to the squares of the standard deviations of the two separate peaks and a last term proportional to the square of the distance between the peak centers.

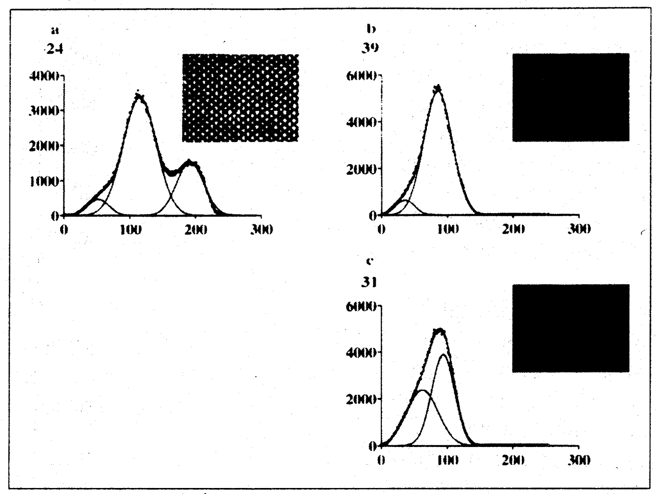
Extension to three peaks gives the formula

$G^2=(A_1/A)S_1^2+(A_2/A)S_2^2+(A_3/A)S_3^2+(A_1A_2/A^2)(X_1-X_2)^2+(A_1A_3/A^2)(X_1-X_3)^2+(A_2A_3/A^2)(X_2-X_3)^2$ Equation 5 where the notation is similar to that above and A is the sum of the three areas.

Image Analysis to Detect the Effects of Pretreatments on Dyeability

The histograms of wool/cotton fabrics before and after pretreatment with resin/CC and unpretreated wool fabric dyed to 3% with C.I. Reactive Red 2 are shown in Figure 5. In the histogram of dyed wool/cotton fabric without pretreatment, #24, note the bimodal pixel distribution about the main histogram showing two well-defined mean values—one for the lighter yarns and one for the darker ones. The pretreated wool/cotton fabric, #39, shows a narrow and symmetrical histogram. Its mean value at the low end of the gray-scale indicates a darker shade than #24 where only the wool yarns were dyed.

Figure 5–Histograms of wool/cotton before and after pretreatments with resin/CC and unpretreated wool fabric dyed to 3% with C.I. Reactive Red: 2 (a)-wool/cotton without pretreatment: (b)-wool/cotton, pretreated: (c)-wool, pretreated.



The histogram of the dyed wool fabric in #31 exhibits approximately the same mean value (Table II) as #39, indicating that the dyeability of wool was not affected by this pretreatment[16-18].

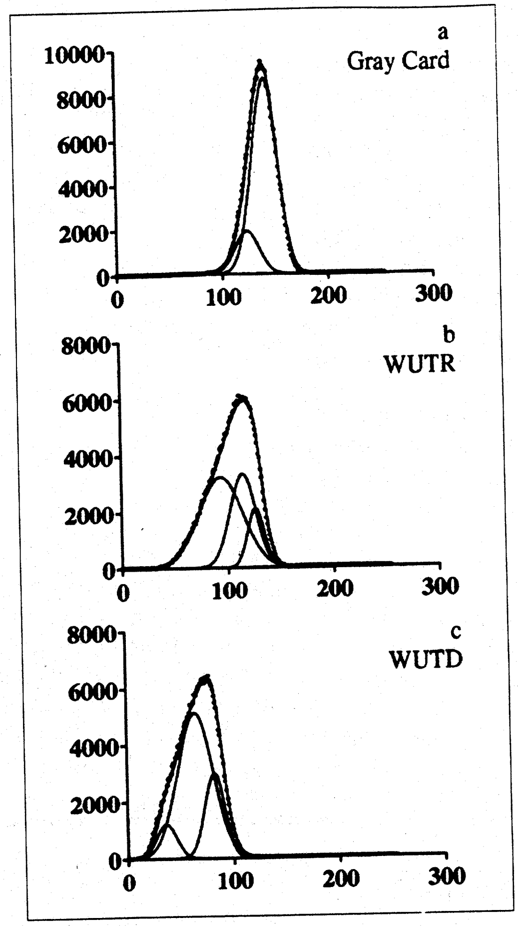
The image analysis system was used to determine the effect of resin/CC on all-wool fabrics. The histograms of untreated wool dyed with C.I. Reactive Red 65 in Figure 6 (b) and C.I. Direct Red 79 in (c) are compared to the gray card in (a) as a standard for uniform color. In Table III the standard deviation of the gray card is much less. However, these dyed fabrics are uniformly colored and their K/S values are reasonable for 3% dyeings. Therefore, these wool fabrics in (b) and (c) can be taken as standards for determining union shades in wool/cotton in place of the gray card. Note that the lower mean value (gray-level) of the histogram of the wool fabric dyed with Direct Red 79 (c) indicates a deeper shade than the wool fabric dyed with C.I. Reactive Red 65 in (b).

Another application for Union Shade Index is shown in Figure 7, where the effectiveness of commercial dye fixatives. Sandene 8425 Liquid (Clariant), Solfix E (Ciba), and Levogen FSE (Bayer) are compared before dyeing the wool/cotton fabrics with 2% C.I. Acid Red 114[19]. These fixatives are compared in Table III. Note that the bimodal histogram for unpretreated wool/cotton union fabric in (a) converges to one peak in (b), (c), and (d), indicating that union shades were achieved with these pretreatments.

Also, note that each of the main histograms was fitted to a superposition of two or three Gaussian peaks. In Figure 7 the curve fit utilized a nonlinear regression program, Abacus, which was written in-house[20]. To perform this analysis, the user sets initial estimates for the height, the histogram peak value or mean, and the peak parameters for 2 or 3 peaks respectively. The program uses the Gaussian Newtonian iteration algorithm to refine these estimates and select the set of parameter values that minimizes the superposition of Gaussian peaks.

Note also in Table m that the standard deviation values practically coincide with the G values. This indicates that merely setting a threshold standard deviation for acceptable union shade would be acceptable without applying the G-value equation. However, for research applications, the G-value can be used to examine the full 0.25 Mbyte data set.

Figure 6–Comparisons of the histograms of unpretreated wool fabrics dyed to 3% with C.I. Reactive Red 2 and C.I. Reactive Red 2, (c)-without pretreatment, dyed with C.I. Direct Red 79.



Digital Image Analysis and Colorimetry

In Figure 8 the relationship between L* and gray-scale mean was examined to determine a complementary relationship between colorimetry and image analysis. L* values were obtained from a BYK Gardner colorimeter. Gray-scale mean values were taken from the histogram data of wool/cotton fabrics pretreated with Sandene 8425 Liquid that were dyed to union shades with 1%, 2%, and 3% C.I. Acid Red 114 and C.I. Direct Red 79 (a), and with C.I. Reactive Red 2 and C.I. Reactive Blue 19 (b). The linear relationships shown in Figure 8 indicate that image analysis would complement colorimetry for on-line monitoring of color quality and shade reproduceability.

Conclusions

An image analysis system can be easily configured from over-the-counter components and used for electronic detection and objective measurement of uniform coloration. This system provides methodology for practical applications including on-line color monitoring in dyeing operations, and for fundamental research in the diagnosis of the effectiveness of textile auxiliaries such as levelers, retarders, and compatabilizers. The histogram display as pixel distribution over a gray or brightness range enables rapid determinations of pass-fail for acceptable uniform shades. A benefit is that thresholds for uniform shade can be arbitrarily set based on the visual perception of any sample as uniformly dyed or on the degree of uniform shade required for the product's end use.

The Level Shade Index provides useful relative rankings of samples dyed under various conditions and a means for quality control of a sample set dyed under the same conditions. For additional information, the binary images of dyed fabrics can be used for mapping to reveal areas of discoloration when gray level thresholds are arbitrary. This information is useful for understanding and correcting dyeing procedures.

The Union Shade Index provides critical information on the unionness of shade in fiber-blended fabrics. The individual gray shades of each fiber component are recorded in the histogram. The histogram's standard deviation can similarly be taken as indicative of union shade. Also, the application of the G-value equation for union shade index provides relative comparisons of composite peak heights,. separations, and breadths that can be used to fine-tune the design of experimental systems to improve union shade.

In the specific applications presented for level shade, one set of cotton fabrics was dyed to unlevel shades because of low dye substantivity while another was dyed to level shades with a substantive dye. The deviations from Gaussian for

Figure 7–Histograms of wool/cotton uniuon fabrics before and after pretreatment with commercial dye fixatives, dyed to 2% with C.I. Acid Red 114; (a)-before pretreatment, (b)-Sandene 8425 Liquid (Clariant), (c)-Solfix E (Ciba), and (d)-Levogen FSE (Bayer).

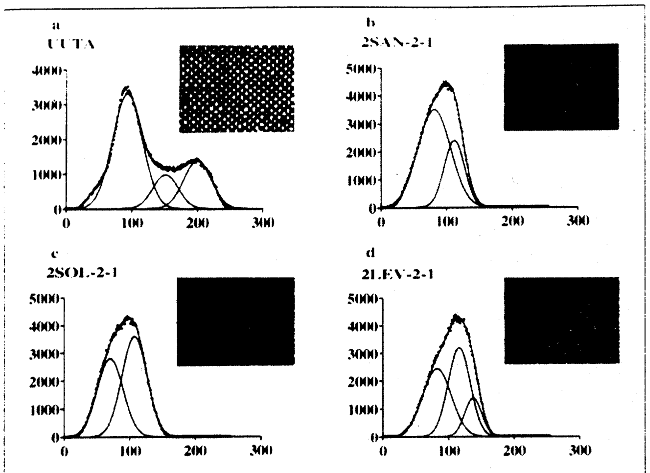
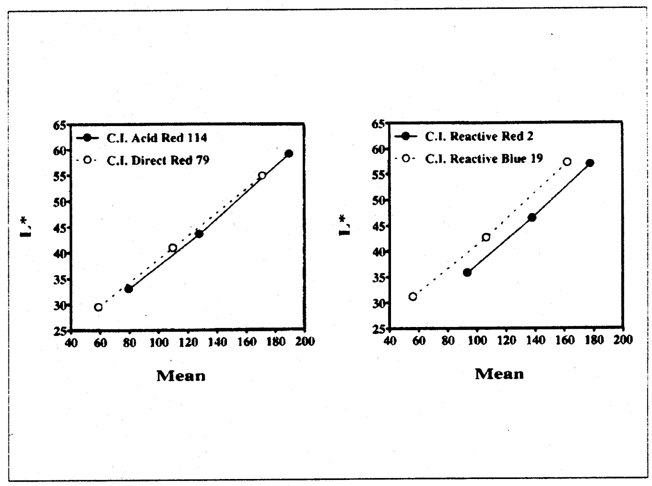


Figure 8–The linear relationships between lightness, L* and the gray-scale mean from the histograms of pretreated wool/cotton dyed uniuon fabrics: (a)-C.I. Acid Red 114 and C.I. Direct Red 79; (b)-C.I. Reactive Red 2 and C.I. Reactive Blue 19.



histograms of unlevel fabrics revealed that skew character and high standard deviations are diagnostic for unlevel shade. In the other applications for union shade, wood/cotton fabrics without pretreatment exhibited a distinctively bimodal histogram characteristic of differential dye uptake because of the dyed wool and undyed cotton yarns. The relative effectiveness for union shade of the different pretreatments, resin/CC versus dye-fixatives, could be fully evaluated by this image analysis system.

Image analysis extends the utility of colorimetry by providing the additional feature of analyzing for level and union shades. It provides objective measurement and can be adapted for real-time applications. □ □ □

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